



## High-field re-entrance of the magnetoelectric effect in LiNiPO<sub>4</sub> investigated in pulsed fields

Fogh, Ellen; Toft-Petersen, R.; Nojiri, H.; Kihara, T.; E. Granroth, G.; B. Stone, M.; Lee, J.; Fritsch, K.; Andersen, Niels Hessel; Vaknin, David

Total number of authors:  
11

Publication date:  
2014

Document Version  
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

### Citation (APA):

Fogh, E., Toft-Petersen, R., Nojiri, H., Kihara, T., E. Granroth, G., B. Stone, M., Lee, J., Fritsch, K., Andersen, N. H., Vaknin, D., & Christensen, N. B. (2014). *High-field re-entrance of the magnetoelectric effect in LiNiPO<sub>4</sub> investigated in pulsed fields*. Poster session presented at 4th Annual Niels Bohr International Academy Workshop-School on ESS Science, Copenhagen, Denmark.

---

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



# High-field re-entrance of the magnetoelectric effect in $\text{LiNiPO}_4$ investigated in pulsed fields



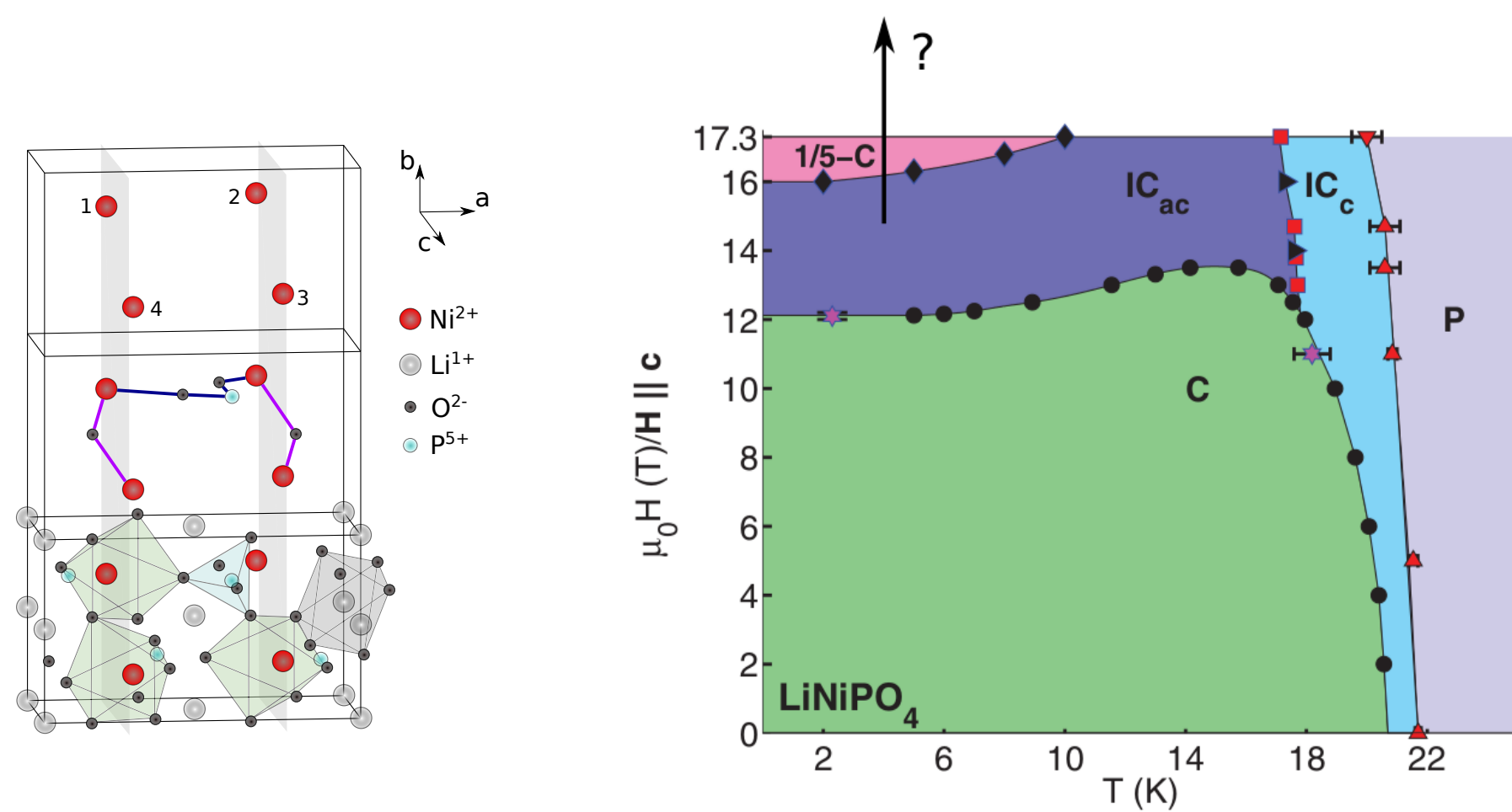
E. Fogh<sup>1</sup>, R. Toft-Petersen<sup>2</sup>, H. Nojiri<sup>3</sup>, T. Kihara<sup>3</sup>, G. E. Granroth<sup>4</sup>, M. B. Stone<sup>4</sup>, J. Lee<sup>4</sup>, K. Fritsch<sup>2</sup>, N. H. Andersen<sup>1</sup>, D. Vaknin<sup>5</sup> and N. B. Christensen<sup>1</sup>

## INTRODUCTION

**Material**  $\text{LiNiPO}_4$  belongs to the family of the magnetoelectric *lithium-ortho-phosphates*. The material exhibits an *XY-like behavior* and the strong *antiferromagnetic interactions* are mainly in the (b,c)-plane.

**Magnetism** The *magnetic phase diagram* of  $\text{LiNiPO}_4$  as function of temperature and applied magnetic field along c has been thoroughly investigated up to 17.3 T in DC fields. Several different antiferromagnetic phases have been characterized [2,3].

**Goal** More transitions have been reported at fields up to 22 T [4] and our goal is to investigate and characterize these.

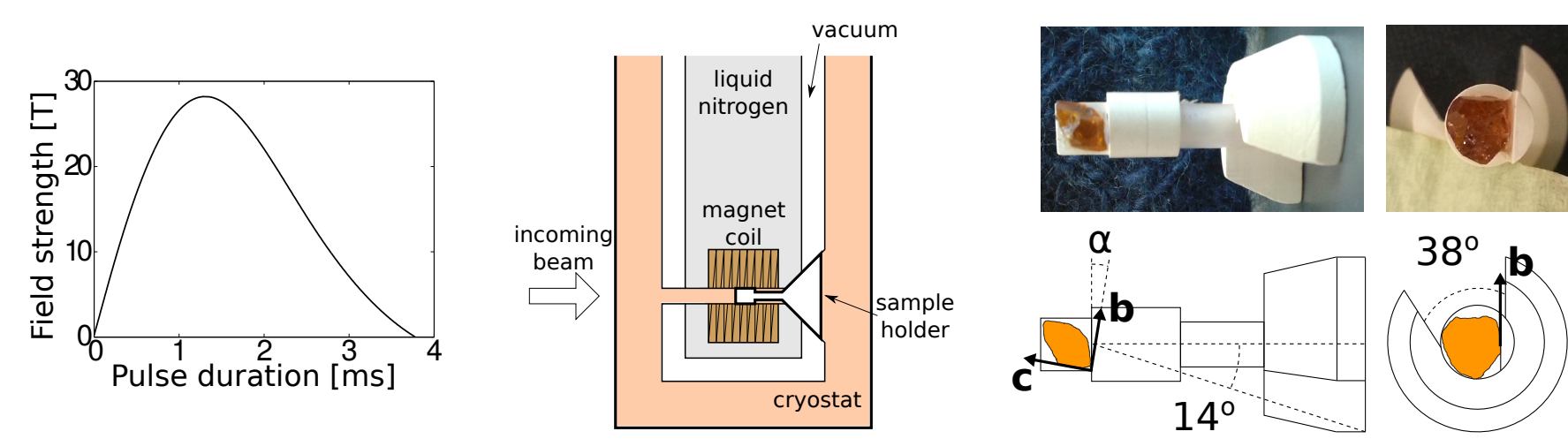


**Figure 1: (Left)** Three unit cells of  $\text{LiNiPO}_4$ . After [1]. **(Right)** The phase diagram of  $\text{LiNiPO}_4$  up to 17.3 T [2]. The arrow shows where we investigated.

## NEUTRON DIFFRACTION IN PULSED FIELDS

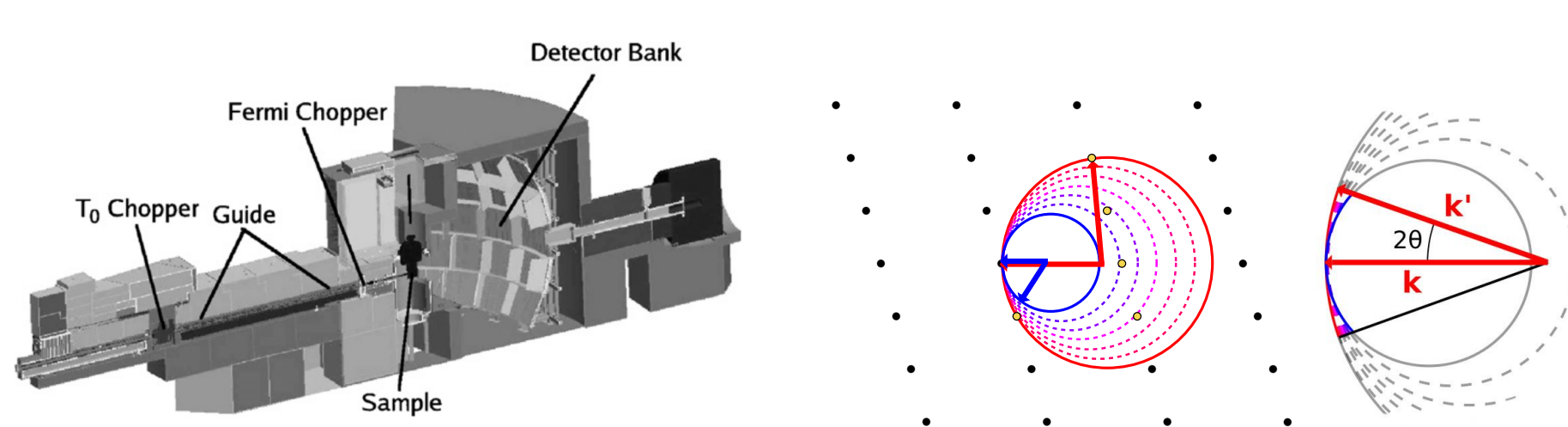
Pulsed magnetic fields are to date the only way to achieve magnetic fields above 17.3 T while performing a neutron experiment.

**Magnet** Current from a *capacitor bank* is dumped into a coil creating a magnet pulse with *maximum strength 30 T*. The pulse duration is  $\sim 5$  ms and a pulse can be released every  $\sim 5$  min to allow the coil to *cool down* in between pulses. The magnet setup requires a special sample holder which restricts the *scattering angle* to maximum  $14^\circ$ .



**Figure 2: (Left)** Magnet pulse shape. **(Middle)** Magnet setup inside cryostat. **(Right)** Sample holder.

**Neutrons** We performed at *Laue neutron diffraction* experiment with wavelengths  $\lambda = [0.2, 0.7] \text{ \AA}$ . The instrument used was *SEQUOIA* at the Spallation Neutron Source at Oak Ridge National Laboratory.



**Figure 3: (Left)** The SEQUOIA instrument **(Right)** Laue diffraction, text book example and what we are actually able to see due to the  $14^\circ$  limit on the scattering angle.

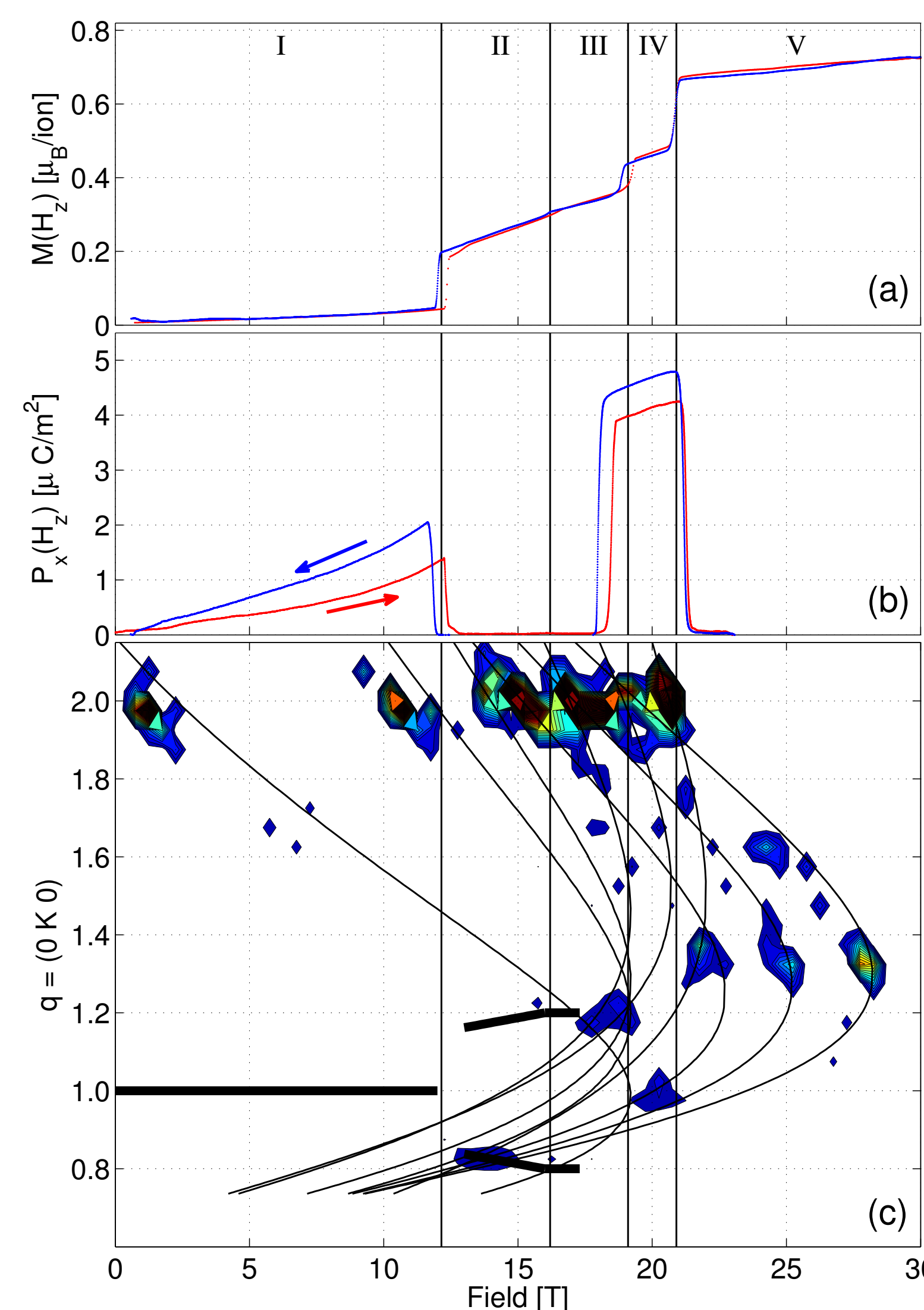
## RE-ENTRANCE OF THE LINEAR MAGNETOELECTRIC EFFECT

The *magnetization* and *electric polarization* were measured in pulsed fields by T. Kihara. The results of both bulk and neutron experiments are presented below. Note that the phases C, IC<sub>ac</sub> and 1/5-C correspond to the phases I, II and III respectively.

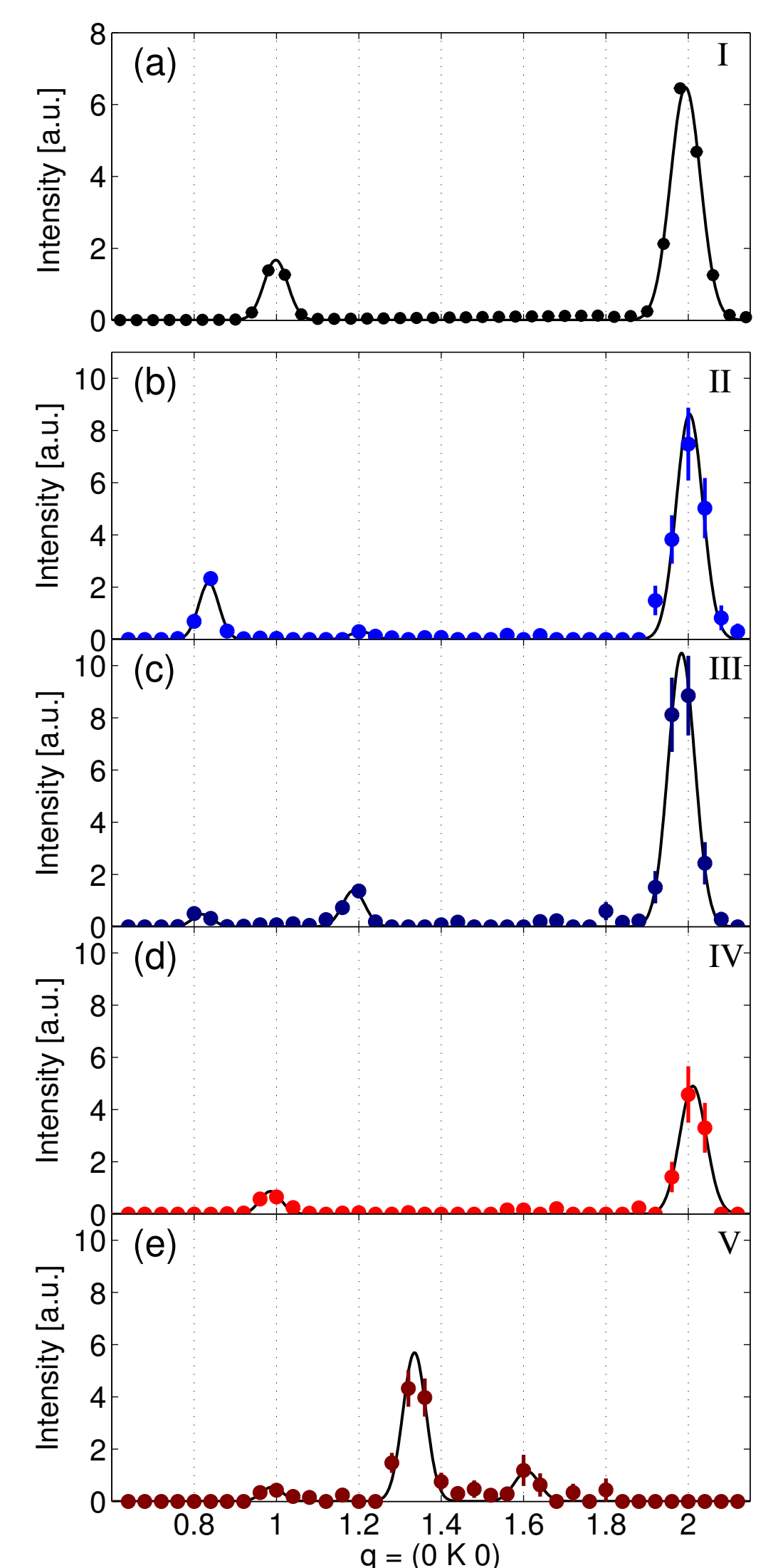
**Magnetization** Five phases were observed up to 30 T and the material is only magnetized  $\sim 1/3 M_S$  at 30 T, where  $M_S = 2.2 \mu_B$ .

**Polarization** A *re-entrance of the linear magnetoelectric effect* was discovered in phase IV. The field was applied along c and the polarization measured along a. The effect is *abscent* in phase V.

**Neutrons** 1274 neutrons were detected with a *field on*! Despite the low statistics we are still able to follow the position of the propagation vector as the field is increased.



**Figure 4: (a) and (b)** Magnetization and polarization respectively as function of field. **(c)** Colorplot of the normalized intensity of the propagation vector  $q = (0K0)$  as function of applied field. The solid curves are field sweeps for different magnet settings. The thick lines are known propagations vectors in the low-field phases.



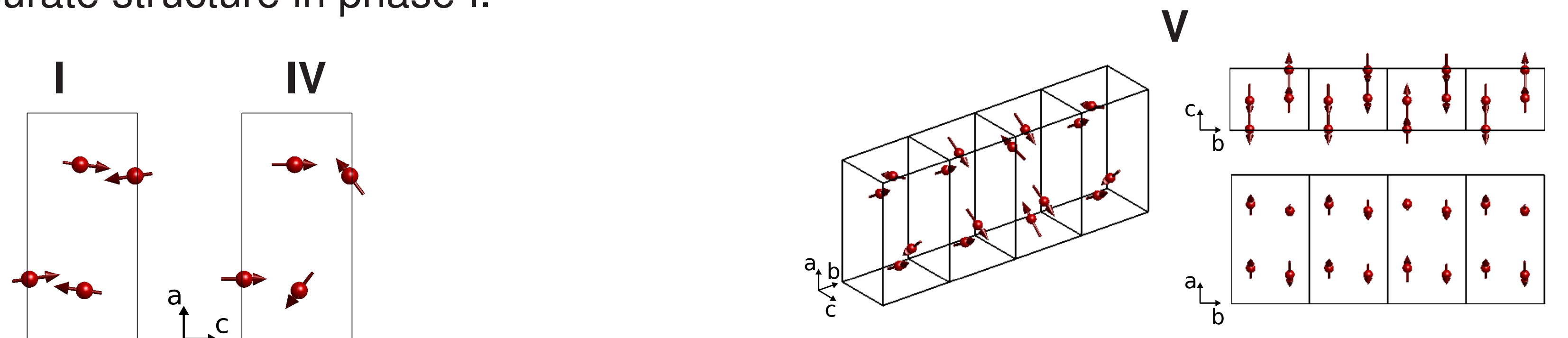
**Figure 5: (a)-(e)** Intensity as function of  $q = (0K0)$  for phases I-V respectively. The positions of the Bragg peaks clearly change from phase to phase.

## POSSIBLE MAGNETIC STRUCTURES IN THE HIGH-FIELD PHASES

The neutron statistics are low and only one Bragg peak has been measured for each phase. However, together with the bulk measurement we can still suggest possible spin structures at high fields.

**Phase IV** The re-entrance of the magnetoelectric effect and the propagation vector  $q = (0,1,0)$  indicate that the magnetic structure is similar to the low-field commensurate structure in phase I.

**Phase V** Using  $M \approx 1/3 M_S$  and the propagation vector  $q = (0,4/3,0)$  Jens Jensen was able to stabilize a meta-stable state which is a superposition of a commensurate and an incommensurate structure.



**Figure 6: Suggested spin structures of phase IV and V.**

## ACKNOWLEDGEMENTS

Jens Jensen from University of Copenhagen is greatly acknowledged for his meanfield calculations and discussions on the high-field behavior of  $\text{LiNiPO}_4$ .

## REFERENCES

- [1] A. Szewczyk et al., *PRB*, **84**(104419), 2011
- [2] R. Toft-Petersen et al., *PRB*, **84**(054408), 2011
- [3] T. B. S. Jensen et al., *PRB*, **79**(092412), 2009
- [4] V.M. Khurstalov et al., *Czech. Jour. of Phys.*, **54**, 2004
- [5] H. Noriji et al., *PRL*, **106**(237202), 2011